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g_J of the $(5s5p)\ ^3P_1$ Level of Cd and the $(6s6p)\ ^3P_1$ Level of Hg by High-Field Double Resonance*

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An optical double resonance experiment at high magnetic fields has determined g_J for the $(5s5p)\ ^3P_1$ level of the even cadmium isotopes to be 1.499846(13), and g_J for the $(6s6p)\ ^3P_1$ level of the even mercury isotopes to be 1.486094(8). Resonance was observed in all cases at a frequency of exactly 24 Gc/sec, and magnetic fields near 11 430 G. At these high fields the Zeeman energy is of the order of 10^{-3} of the fine structure separations of the triplet terms of the $(nsnp)$ configuration, and the $\Delta m = \pm 1$ transitions are split by 9.51(7) G for Cd, and by 2.99(7) G for Hg. This splitting represents several linewidths in the case of Hg, and many linewidths in that of Cd. The average field of the two $\Delta m = \pm 1$ transitions, however, determines g_J to high precision independent of second-order corrections.

Author

I. INTRODUCTION

THE double resonance[1,2] and level crossing techniques[3,4] have been used in extensive studies of hyperfine structure (hfs) in the lowest lying $(nsnp)\ ^3P_1$ level of mercury,[5–11] cadmium,[12–17] and zinc.[18–20] Sufficient sensitivity has been obtained to allow the determination of the hfs, and consequently the nuclear moments, of radioactive isotopes with half-lives as short as a few hours.[15,16]

While the level crossing method has the great advantage in practice of doing away with all radio-frequency and microwave apparatus, aside from nuclear magnetic-resonance (NMR) magnetometers, it allows a determination of only the ratio of the hyperfine interaction constants to g_J, and an independent measurement of g_J must therefore be made to determine these constants to high precision.[16] While g_J can of course be measured by double resonance in the odd isotopes at various fields, or by observing both double resonance and level crossings,[9,13] it is most directly found from double resonance in the even isotopes of the element.

In principle, the higher the frequency and the greater the magnetic field, the more accurate the determination of g_J. In a series of experiments designed to measure g_J of the lowest lying $^3P_1$ level of zinc, cadmium, and

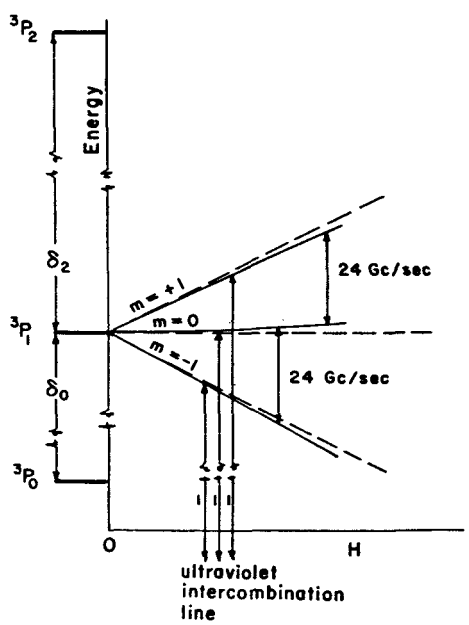

FIG. 1. Zeeman effect of the $^3P_1$ state of the even isotopes of zinc, cadmium and mercury, showing the effect of second-order interaction with the other fine structure levels of the configuration.

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BLE I. Atomic constants of Zn, Cd, and Hg. $\lambda(^3P_1)$ and $\lambda(^1P_1)$, the wavelengths of the resonance lines of the lowest lying $(nsnp)$ configuration, and δ_2 and δ_0, the fine structure separations of the triplet terms, are taken from C. E. Moore.[a]

Atom	τ ($^3P_1$) (sec)	τ ($^1P_1$) (sec)	$\lambda(^3P_1)$ (Å)	$\lambda(^1P_1)$ (Å)	δ_2 (cm^{-1})	δ_0 (cm^{-1})
Zn	$2.00(20)\times10^{-5}$ [b]	$1.38(5)\times10^{-9}$ [c]	3077	2139	388.927	190.082
Cd	$2.39(4)\times10^{-6}$ [d]	$1.66(5)\times10^{-9}$ [e]	3261	2288	1170.866	542.113
Hg	1.18×10^{-7} [f]	0.3–1.6×10^{-9} [g]	2537	1849	4630.677	1767.220

[a] C. E. Moore, *Atomic Energy Levels* (U. S. Government Printing Office, 1949–58).
[b] See Ref. 19.
[c] See Ref. 20.
[d] See Ref. 23.
[e] A. Lurio and R. Novick, Phys. Rev. **134**, A608 (1964).
[f] See the last paper of Ref. 22.
[g] A. C. G. Mitchell and M. W. Zemansky, *Resonance Radiation and Excited Atoms* (Cambridge University Press, Cambridge, 1961), 2nd ed., p. 147.

mercury to high precision (it is $\frac{3}{2}$ on the basis of LS coupling), we therefore chose to work at a frequency of 24 Gc/sec, and a field near 11 400 G—approaching the limit attainable with the available 12-in. electromagnet when operating with a gap of 2 in.

The $\Delta m=\pm1$ transitions for these states coincide at low magnetic fields, but at high fields interaction with the neighboring fine structure terms of the configuration (and to a negligible degree with levels of other configurations) splits the resonances into two well-resolved components, as shown in Fig. 1. Precise measurement of the splitting of the two resonances therefore serves also as a check on the theory of the second-order fine structure interactions.

II. THEORY

Signal Strengths

It is well known that double resonance can be observed between hyperfine or Zeeman states excited by resonance radiation in a variety of ways. Population differences can be produced by resonance radiation that is polarized, nonisotropic, or confined to a narrow wavelength interval, and all of these methods have been put to practical use.[1,2,6]

To dispense with ultraviolet polarizers, we relied on the latter two effects and used the experimental geometry shown in Fig. 2. Only lamps containing the natural metal were used. In the case of cadmium, the Zeeman shift of the $m=\pm1$ states at 11 400 G is somewhat greater than the isotope shifts and the hyperfine splittings of the natural cadmium isotopes (and the optical Doppler width),[14] and only the $m=0$ state is therefore illuminated. It is then readily calculated in terms of the transition probabilities that at double resonance the resonance fluorescence at 90° is reduced by a factor of $\frac{1}{4}$.

For mercury, on the other hand, the isotope shifts and hyperfine splittings are comparable to the Zeeman shift of the $\Delta m=\pm1$ states,[21] and we must rely mainly on the nonisotropic nature of the resonance radiation. In the least favorable case, on the assumption that all three states are equally illuminated, it is calculated that the resonance fluorescence at 90° is reduced by a factor of $\frac{1}{12}$ at double resonance.

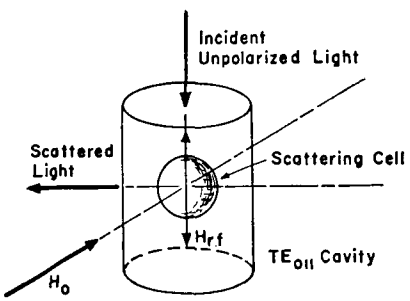

FIG. 2. Geometry of the experiment.

Linewidths

Several effects determine the linewidth and shape of the double resonance effect, and have all been considered in detail elsewhere. Most fundamentally, the natural lifetime τ of the state gives a Lorentzian line shape with full width at half-maximum of $g_J\mu_0\Delta H_n=\Delta\nu_n=1/\pi\tau$.[1,6] The natural linewidths for zinc, cadmium, and mercury calculated from the lifetimes in Table I are listed in Table II.

If the rf magnetic field is strong enough to induce many transitions during the lifetime τ, the resonance will be power broadened.[1,6] In practice the rf power is always attenuated to the point where this effect is small, and it will therefore not be considered further.

Double resonance owes its high resolution to the fact that Doppler broadening is determined by the radio rather than by the optical frequency. At microwave frequencies, however, the Doppler linewidth $\Delta\nu_d=(\nu/c)\times(8NkT\ln2/M)^{1/2}$, where N is Avogadro's number and

TABLE II. Theoretical and observed linewidths in milligauss. ΔH_{calc} is taken as the sum of the natural, Doppler, magnetic field, and wall collision widths.

Atom	ΔH_n	ΔH_d	ΔH_m	ΔH_w	ΔH_{calc}	ΔH_{obs}
Zn	8	29	50	37	124	...
Cd	68	18	50	26	162	175
Hg	1295	10	50	15	1370	1300

[21] F. Bitter, S. P. Davis, B. Richter, and J. E. R. Young, Phys. Rev. **96**, 1531 (1954).

M is the molecular weight, may not be altogether negligible, as is shown in Table II.

Inhomogeneity of the magnetic field over the scattering sample contributes a linewidth ΔH_m that can often be reduced by careful alignment of the pole pieces. We found, however, that as our magnetic field approached 11 400 G, its homogeneity fell off rapidly due presumably to uneven saturation. We estimate that $\Delta H_m = 50$ mG over a 5-mm sample.

Collisions with the walls of the scattering cell effectively shorten the lifetime of the excited state, and contribute a wall-quenching linewidth $\Delta\nu_w$ which depends mainly on the size of the cell. We have made estimates of $\Delta\nu_w$ in Table II on the assumption that $\Delta\nu_w = 1/\pi\tau_w = (3NkT/M)^{1/2}/\pi a$, where τ_w is the time for an atom at the temperature of the optimum vapor pressure to travel the radius a of the scattering cell.

Collisions between the scattering atoms will broaden the resonance at high vapor densities, while multiple scattering of the optical photons may actually decrease the linewidth (coherence narrowing).[22,23] Both of these effects may be avoided by working at low enough temperatures.

Quenching by atomic or molecular contaminants in the scattering cell, on the other hand, may contribute a linewidth $\Delta\nu_c$ which cannot be easily estimated in advance, and cannot be reduced once the cell is made. We shall see that possibly except for zinc we found no evidence of quenching of this kind.

Zeeman Effect

Interaction with the two neighboring triplet levels of the $(nsnp)$ configuration contributes a term which is of the order of the (Zeeman energy)^2/(fine structure energy) $\approx 10^{-3}\times$(Zeeman energy) to the energy of the $m=\pm 1$, 0 states. More precisely, from perturbation theory,[24]

$$W_{+1} = g_J\mu_0 H - \frac{\alpha^2(g_S-g_L)^2\mu_0^2H^2}{4\delta_2}, \tag{1a}$$

$$W_0 = \alpha^2(g_S-g_L)^2\mu_0^2H^2\left(\frac{2}{3\delta_0}-\frac{1}{3\delta_2}\right), \tag{1b}$$

$$W_{-1} = -g_J\mu_0 H - \frac{\alpha^2(g_S-g_L)^2\mu_0^2H^2}{4\delta_2}, \tag{1c}$$

where μ_0 is the Bohr magneton, α is the mixing coefficient which indicates the departure from Russell-Saunders coupling, and δ_0 and δ_2 are the magnitude of the fine structure separations. We adopt the convention that g_J is positive. Interaction with the singlet term of the configuration, and with terms of other configurations, contributes less than one part in 10^6 to the energy, and third-order terms vanish.

For double resonance at a fixed frequency ν_{dr}, the field H^+, for which $m=0\rightarrow+1$, is greater than H^-, for which $m=0\rightarrow-1$. To within one part in 10^6 we find from Eq. (1) that in terms of the average field $\bar{H}=(H^++H^-)/2$

$$g_J = h\nu_{dr}/\mu_0\bar{H}. \tag{2a}$$

This becomes

$$g_J = g_p(\nu_{dr}/\bar{\nu}_p), \tag{2b}$$

if the field is measured in terms of the NMR frequency ν_p of protons. g_p is defined such that the proton magnetic dipole-moment operator is $\boldsymbol{\mu}_p = g_p\mu_0\mathbf{I}_p$. For protons in mineral oil we will take $g_p = 3.041978(3)\times10^{-3}$, from the average of the measurements of g_s/g_p for protons in mineral oil of Koenig, Prodell, and Kusch,[25] and Beringer and Heald,[26] and the recent measurement of g_s of Wilkinson and Crane.[27]

For the separation of the two resonances we find that

$$\Delta H = H^+ - H^- = \frac{\alpha^2(g_S-g_L)^2\mu_0\bar{H}^2}{g_J}\left(\frac{4}{3\delta_0}-\frac{1}{6\delta_2}\right), \tag{3a}$$

where δ_0 and δ_2 are in ergs. When the field is measured in terms of the proton frequency,

$$\Delta\nu_p = \frac{\alpha^2(g_S-g_L)^2\bar{\nu}_p^2}{cg_pg_J}\left(\frac{4}{3\delta_0}-\frac{1}{6\delta_2}\right), \tag{3b}$$

where δ_0 and δ_2 are in cm^{-1}.

III. EXPERIMENT

A schematic illustration of the experiment is shown in Fig. 3. Resonance radiation from an rf lamp was focused with a quartz condensing lens onto a small cell containing cadmium or mercury vapor. The cell was located within a microwave cavity between the poles of a 12-in. electromagnet. This cavity in the case of cadmium also served as an oven to control the vapor density in the scattering cell.

Resonance fluorescence of the atomic vapor was observed with a photomultiplier at an angle of 90°. A light pipe allowed the photomultiplier to be removed from the magnetic field without loss of solid angle. A glass color filter effectively removed all scattered light except the resonance radiation.

The microwave cavity was tuned to resonance with a klystron kept at a frequency of exactly 24 Gc/sec, the field being modulated at a low audio frequency, typically 37 cps, by small rectangular coils attached to the pole faces. At resonance, the light scattered at 90°

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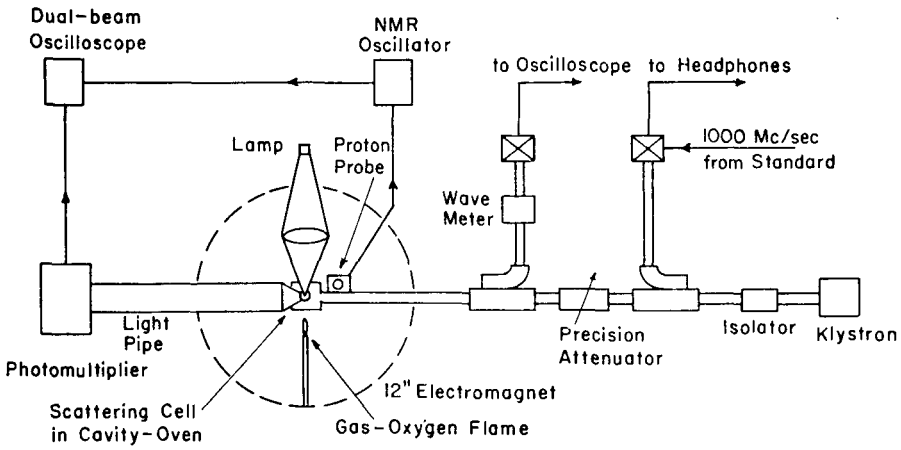

FIG. 3. Schematic diagram of the experiment.

changed in intensity, and the signal from the photomultiplier was displayed on an oscilloscope.

Field measurements were made with an NMR magnetometer, whose small mineral-oil probe was located as close to the scattering cell as possible. The offset correction was measured with a second probe and oscillator.

Optics

The cadmium lamp used consisted of a small quartz cylinder, 1.5 cm in diameter and 2.5 cm long, carefully baked out, purged with an rf discharge in argon and then filled with a small amount of distilled natural cadmium and about 1 torr of spectroscopically pure argon. It was identical to the lamps previously used in this laboratory for several level crossing and double resonance experiments.[13,14] It was excited by being placed, without cooling, in the tank coil of a Hartley oscillator operating in the vicinity of 30 Mc/sec. Experience has shown that these lamps furnish about 1 W (total output over 4π solid angle) in the 3261-Å intercombination line.

For mercury an Osram lamp was used that had the outer jacket removed, and was cooled with a gentle air stream to eliminate self-reversal. It too was excited with a radiofrequency oscillator operating near 30 Mc/sec and was run at the same current specified by the manufacturer for operation at 60 cps.

The scattering cells were designed to have as small an effect as possible on the electrical properties of the microwave cavity. They were very thin walled quartz bubbles, 5 mm in diameter, blown at the end of a length of 2 mm outer diameter quartz tubing, which, when cut off at a length of 5 cm, served as the tail of the cell. These cells were baked out at 1000°C for a day or longer, purged with a Tessla coil for several minutes, and filled with a small quantity of distilled metal, all under very high vacuum (less than 10^{-8} Torr for the last stage). The light pipe used to remove the RCA-1P28 photomultiplier from the vicinity of the magnet was a glass tube aluminized on the inside, 1 in. in diameter, and about $2\frac{1}{2}$ ft long. To pass the 3261-Å line of cadmium, or the 2537-Å line of mercury, and exclude other scattered light, a Schott UG-11 or UG-5 colored glass filter was cemented to the end of the light pipe.

Microwave Cavity and Oven

The TE_{011} cylindrical aluminum cavity oven used for cadmium is shown in Fig. 4. It had an internal diameter of 1.4 cm, a Q of about 4000 when loaded with the cell, and was coupled about 50% to the microwave line. A hole 6 mm in diameter at the top of the cavity, below cutoff at 24 Gc/sec, allowed illumination of the scattering cell. Small slits in the side of the cavity, also below cutoff, allowed the light scattered at 90° to be observed.

The waveguide connecting the cavity to the microwave line was thinned to provide thermal insulation. The cavity was heated with a small gas-oxygen flame, the temperature being monitored by a small copper-constantin thermocouple. Thermal regulation was provided

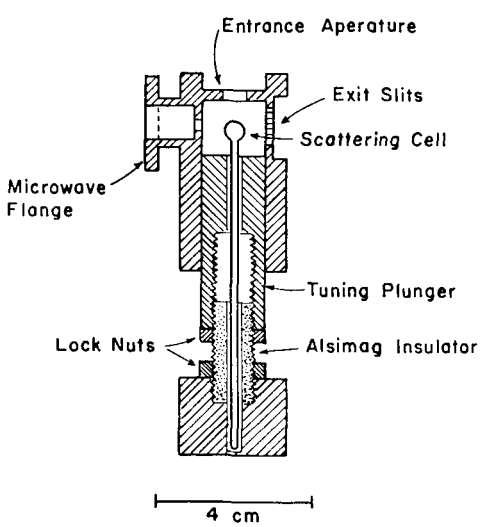

FIG. 4. The cavity oven used for cadmium.

by a Honeywell R7086A thermocouple-activated regulator that played a stream of cool air against the cavity when the thermocouple voltage exceeded a preset figure.

The long tail of the scattering cell passed through an aluminum tuning plunger, and an insulating refractory section, and terminated in the aluminum cylinder shown in the bottom of Fig. 4. This cylinder was heated with another gas-oxygen flame, and its temperature regulated with a separate regulator unit. It was always kept at least 40°C cooler than the oven, and consequently determined the cadmium vapor pressure.

For mercury, in an attempt to gain a higher Q, a thin-walled copper cavity was used that was kept at room temperature. With a brass tuning plunger, a loaded cavity Q of about 8000 was obtained. The tail of the cell was usually kept at room temperature, but could also be cooled in an ice bath.

Microwave Measurements

The Varian VA-98E klystron used in this experiment is an extremely stable tube that oscillates only over the region from 23.6 to 24.4 Gc/sec, with an average output of about 30 mW. To achieve maximum stability, we used batteries for both the heater and repeller voltages, and a well-regulated power supply for the beam voltage. No electronic stabilization of the tube was employed. During a run it was kept manually to within an audio-beat note of the 24th harmonic of the 1000 Mc/sec output of the laboratory's frequency standard. This represents a stability of about one part in 10^6, and is therefore quite adequate for the purpose of this experiment.

Field Measurements

The proton probe of the NMR magnetometer used for field measurements consisted of a small spherical cavity filled with mineral oil drilled in the center of a teflon spool. The inductance for a transistorized marginal oscillator was wound on the spool which was then placed in a brass or copper shield. It was located as close as possible to the scattering cell (about 4 cm away), and the output signal of the marginal oscillator was displayed with the double resonance signal on a dual beam oscilloscope. The NMR frequency, near 48 Mc/sec, was measured with a Hewlett-Packard direct reading frequency counter whose reference frequency was taken from the laboratory standard. The offset correction was measured by removing the oven, placing a second probe driven by another identical oscillator at the scattering cell location, and measuring the beat frequency ($\approx$4 kc/sec) of the two oscillators with the frequency counter. A pentode mixer gave the difference frequency without excessive cross coupling of the two oscillators.

The offset correction was found to depend on the field history, and a correction was therefore made after each field measurement.

IV. RESULTS

For cadmium the onset of power broadening was observed when about 5 mW of microwave power were incident on the cavity, in rough accord with our preliminary estimates based on the lifetime of the $(5s5p)\ ^3P_1$ level, and the electrical properties of the cavity. With oscilloscope display giving a detector bandwidth of about 1 kc/sec we succeeded in obtaining a signal-to-noise ratio of about 30 for both the $\Delta m=\pm 1$ double resonance transitions [Fig. 5(a)]. The observed linewidth (Table II) shows no evidence of contamination broadening.

The shorter lifetime of the $(6s6p)\ ^3P_1$ level of mercury was found to require for maximum signal strength somewhat higher rf fields than the VA-98E klystron and aluminum cavity could provide. A higher Q copper cavity subsequently used for mercury just allowed the level of power broadening to be reached. The observed resonances [Fig. 5(b)] had a signal-to-noise ratio of about 5. It should be recalled that because of the illumination of the $m=\pm 1$ states the mercury signals are expected to be about 3 times weaker than those of cadmium. The additional discrepancy in signal strength can be attributed to the somewhat weaker output of the mercury lamp. The linewidth was in agreement with expectations (Table II).

We had originally hoped to extend our measurements to the $(4s4p)\ ^3P_1$ level of the even zinc isotopes, although we were aware that the long lifetime of this level would produce serious quenching of the excited state atoms against the wall of the scattering cell. We, in fact, made several runs using narrow-band phase-sensitive detection with time constants as long as 5 sec, but failed to detect either double resonance or fluorescence. Beyond the quenching and broadening mechanisms listed in Table II, we are inclined to attribute this to contaminants produced by the high cell temperature required for zinc.

The magnetic fields at which double resonance was observed for cadmium and mercury are listed in Table III. From Eq. (2) we then find for the $(5s5p)\ ^3P_1$ level of cadmium that

$$g_J=1.499846(13)=\tfrac{3}{2}-154(13)\times 10^{-6},$$

in good agreement with the values $g_J^{111}=\frac{3}{2}-171(9)\times 10^{-6}$ and $g_J^{113}=\frac{3}{2}-157(9)\times 10^{-6}$ found for the odd isotopes from level crossings[13] and zero-field double resonance[12] (we have here recalculated g_J^{111} and g_J^{113} taking $g_p=3.041978\times 10^{-3}$).

Likewise, we find for the $(6s6p)\ ^3P_1$ level of mercury that

$$g_J=1.486094(8)=\tfrac{3}{2}-13\,906(8)\times 10^{-6}.$$

This is in reasonably good agreement with a recent preliminary value of $g_J^{199}=1.486118(16)$ found by Smith,[28] who considered both his own level-crossing

[28] W. Smith (private communication).

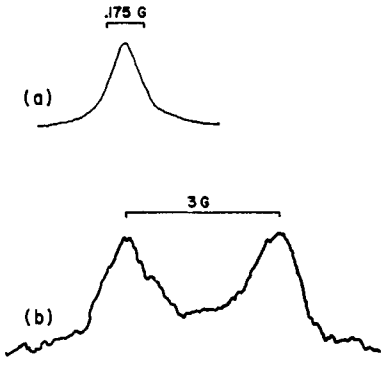

FIG. 5. Oscilloscope traces of the double resonance signals: (a) is one of the $\Delta m = \pm 1$ cadmium transitions, (b) is the sum of these two transitions for mercury, split by the second-order interactions.

study of Hg^{199}, and the results of low-field double resonance.[11] It is also in agreement with the less precise value 1.486350(300) found by Dodd[29] from double resonance in the even isotopes. It is in disagreement, however, with the self-consistent values $g_J^{199} = 1.486147(10)$ and $g_J^{201} = 1.486156(18)$ calculated by Kaul in his thesis[9] from his study of level crossings, and the low-field double resonance results.[6,11]

For cadmium the known lifetimes of the $^3P_1$ and $^1P_1$ levels allow α to be calculated directly from the relation

$$\frac{\beta^2}{\alpha^2} = \frac{\tau(^1P_1)\lambda^3(^3P_1)}{\tau(^3P_1)\lambda^3(^1P_1)}, \tag{4}$$

and the normalization condition $\alpha^2+\beta^2=1$. Using the lifetimes and wavelengths of Table I we find that $\alpha = 0.99900(5)$ and $\beta = -0.0448(11)$. The phase convention of Condon and Shortley is used to determine the sign of β.[24] From Eq. (3) the splitting of the resonances is then calculated to be $\Delta\nu_p = 40.245(4)$ kc/sec, or $\Delta H = 9.452(1)$ G. This is seen from Table III to be 0.255 kc/sec lower than the experimental value, but just within the experimental uncertainty.

Knowing α and β independently from the lifetimes, we are in a position to determine the sum of the relativistic and diamagnetic corrections to g_J. Theoretically

$$g_J = \tfrac{1}{2}\alpha^2(g_L+g_S)+\beta^2 g_L+\Delta g_{\text{rel}}+\Delta g_{\text{diam}}. \tag{5}$$

Taking $g_L = 1$,[30] and $g_S = 2.002319$,[27] we find that[31]

$$\Delta g_{\text{rel}}+\Delta g_{\text{diam}} = -318(40)\times 10^{-6}.$$

Since for mercury the lifetime of the $^1P_1$ level is poorly known, the sum of the relativistic and diamagnetic corrections cannot be found. Instead, however, we may use Eq. (5) neglecting these corrections to obtain $\alpha = 0.9849(4)$ and $\beta = -0.1733(24)$. We then calculate from Eq. (3) the splitting of the mercury resonances to be $\Delta\nu_p = 12.468(8)$ kc/sec or $\Delta H = 2.928(2)$ G. It is interesting to note that this is lower than the experimental value by 0.252 kc/sec, nearly the same as in the case of cadmium. Since the measurement of the splitting ΔH is not susceptible to the same systematic errors as the absolute field measurements, the uncertainties in ΔH given in Table III must be considered quite conservative, and this discrepancy may be significant.

TABLE III. Measured fields for double resonance in cadmium and mercury, in terms of the NMR frequency of protons in mineral oil, and in G, taking for $1/2\pi\times$ the gyromagnetic ratio 4.25760(4) kc/sec-G.[a] A series of runs were made for each atom, care being taken to randomize systematic errors from run to run by slightly relocating the cell and probe within the field, reversing the polarity of the magnet, varying the modulation frequency, changing the vapor pressure, reassembling the optics, etc. The uncertainties quoted are 3 times the standard deviation of the means of the individual runs.

Atom	H^+	H^-	ΔH
Cd	48 696.91(66) kc/sec 11 437.64(19) G	48 656.40(45) kc/sec 11 428.13(15) G	40.50(28) kc/sec 9.51(7) G
Hg	49 133.45(35) kc/sec 11 540.17(14) G	49 120.73(38) kc/sec 11 537.19(14) G	12.72(26) kc/sec 2.99(7) G

[a] R. L. Driscoll and P. L. Bender, Phys. Rev. Letters 1, 413 (1958).

V. DISCUSSION

While an accuracy of about one part in 10^5 has been attained in the field measurements reported in this experiment, for cadmium this represents an uncertainty of one linewidth, and can certainly be improved upon. In retrospect we believe that higher precision could have been realized at somewhat lower frequencies and fields. Most of our uncertainty can be ascribed to the inhomogeneities which crept in as the field approached 11 400 G. Had we worked at half the present field and frequency, for example, the field would have been considerably more uniform, the scattering cell would have been twice as large (and easier to construct and more durable), the Doppler and wall collision linewidths halved, and the exit and entrance apertures increased in area by four. It is probable that under these circumstances we would have had sufficient signal strength to observe double resonance in zinc, and that the cadmium resonance could have been measured to a small fraction of its width.

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[29] J. N. Dodd, Proc. Phys. Soc. (London) 78, 65 (1961).

[30] This neglects effects due to nuclear motion, which are expected to contribute a correction to g_L of the order of a few ppm. See A. Abragam and J. H. Van Vleck, Phys. Rev. 92, 1448 (1953).

[31] The theoretical values of $g_J = \frac{3}{2} - 18(80)\times 10^{-6}$ and $\Delta g_{\text{rel}} + \Delta g_{\text{diam}} = -135(81)\times 10^{-6}$ given in Ref. 13 are in error. These values were calculated from Eq. (13), Ref. 13 on the basis of outdated lifetimes—not those given in Table I, Ref. 13. To the best of our knowledge, the remaining results in that work are self-consistent.